



Fermi National Accelerator Laboratory

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SSC GTAW Welding Camera System

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Introduction

Fermi National Accelerator Laboratory has designed and installed a four camera Gas Tungsten Arc Welding vision system which employs a unique filtering system for the welding of prototype superconducting magnets for the Superconducting Super Collider at its industrial facility in Batavia, Illinois. The vision system was developed to overcome hazardous working conditions due to space limitations and high ozone concentrations, as well as, provide superior control over the welding process.

The SSC 50mm Magnets

The magnets being produced are 55 ft. (16.7 m) long, 13 in. (34 cm) diameter assemblies containing superconducting coils. They will be connected in series in an underground ring 53 miles in circumference. The magnetic field produced by them will steer two beams of protons in opposing circular routes, ultimately causing them to collide at high energies. Scientists will study the results of the collisions to gain knowledge about the basic constituents of matter.¹

Skin Welding Operation

One critical step in the production of a superconducting magnet is the skin welding operation. During this operation, skin halves are welded over the coil and iron of the magnet under vertical preload. The skin halves are welded to a backing strip ("welding key") in a double bevel v-groove joint. The welding process used is GTAW (Gas Tungsten Arc Welding) with cold wire feed. The GTAW skin welding operation takes place in a 60 ft. long multi-cylinder hydraulic press with unique tooling (figure #1). Built within the press is a two carriage linear welding system. The welding torch carriages ride on parallel ball bushing tracks, driven by a chain drive, with two

¹ Rodger Bossert, Private Communications

torches per carriage mounted in the horizontal position. The torches are mounted within a framework which is spring loaded horizontally against the magnet assembly. The welding key has an additional central v-groove along its entire length. The carriage has guide rollers which roll in this groove and adjust the whole carriage in the vertical direction. The torches are individually adjustable with reference to the center of the guide wheel groove. Also, the cold wire feed tips are mounted on the individual torch frames within the carriage. The wire feed tip is adjustable with respect to the torch tip in both the vertical and horizontal plane.

The skin serves a dual purpose in the magnet structure. First, the skin is the structural support for the coils of the magnet. The magnet coils require an iron mass surrounding them for efficiency. The iron mass requires the mechanical stability to resist the intense magnetic forces generated by the coils. In operation, the magnetic field forces the iron mass away from the coils when energized. If the iron mass does not have sufficient preloading at operating temperatures to resist this force, the coil will not be superconducting².

Secondly, the skin halves form the wall of a single wall pressure vessel which contains the liquid helium used to cool the magnet. The weld quality itself must be sufficiently high to guarantee the integrity of the pressure vessel wall. The weld is produced to the intent of the ASME (American Society of Mechanical Engineers) Boiler and Pressure Vessel Code. The ASME Boiler and Pressure Vessel Code requires that thorough calculations and drawings be documented. Some of the many things required by the code are examination of all materials, fabrication materials which are traceable to certified material, and documentation of Charpy impact tests. Implicit in all these requirements is a well documented quality control system³.

System Redesign

The original welding control and carriage system was designed and built by Magnatech Industries of East Granby, Connecticut. The original custom controller featured automatic gap control, servo wire feed, current and pulsed current control. The original carriage provided operators with hand

² Jim Strait, "50 mm Collider Dipole Magnet: Requirements and Specifications", Article Title: "Mechanical Design"; Base Line Issue; Rev. #3; Aug. 16, 1991

³ Asme Pressure Vessel Code, Section 8, Div. #1, 1983

adjustments at the welding carriage to vary wire feed tip placement and torch position.

This system was plagued by a number of problems. The first was unexplained shut-downs of the welding system. Welders would often be in the middle of a seemingly successful run only to have the system shut-down by unexplainable system faults. Another problem was high ozone concentration. The welding process itself occurs in a very confined area within the press. Welders were required to be very near to the weld in order to make hand adjustments at the carriage. The amount of air entering this area of the machine was not sufficient to bring ozone levels down. Vacuum proved to be a good temporary solution. A third problem was UV radiation. The space inside the press was so confined that welders helmets could not be practically worn while welding. The resulting innovation was hand shields and clothing which covered exposed skin, however this provided only a temporary solution to the problem. The decision was made to solve the confinement problems by moving the operators as far away from the welding point as possible.

To move the welders away from the carriages required a remote viewing system. Camera systems from various suppliers were demonstrated and even quoted. All of these systems were severely limited by the existing amount of space. Borescope type lensing produced too much distortion. Pentaprism type reflectors and mirror type reflectors resulted in partial focus of the weld puddle area due to the steep angle required. Laser vision triangulation systems were considered but found to be cost prohibitive. The solution turned out to be a microcamera and a carriage redesign.

Fermilab engineers designed and built new carriages which featured four small water cooled cameras with remote set-up/weld jog, set-up lighting, and a unique light filter arrangement (figure #2 and #3). Also, joystick control of wire feed tips and torch was added. The custom wire feed servo drives and automatic gap control devices designed by Magnatech Industries were re-used in this design since these devices had good service records and had not needed replacement. The custom controller was also re-used with the addition of a first fault indicator which is presently being designed and built by Fermi engineers.

The redesign of this system incorporated several innovations. The new system places two operators at a control console where they make position adjustments to wire feed tips, torch-work gap, torch to base distance, and

wire feed rate. Small linear actuators were required to adjust the wire feed tips and torch at the welding carriage. Small linear motors were available, but nothing that would withstand near-welding temperatures. The positioning motors selected (Newport Corp.) for torch and wire feed tips were modified to be water cooled. Water jackets of aluminum are fitted around the cylindrical body of the linear motors in the area of the windings. Wire feed tips of alumina ceramic were made to provide a measure of safety against torch to frame shorts and allow the tip to be placed nearer the puddle than the previously used stainless steel feed tips. The positioning motor controller (Newport Corp.) has velocity control, joystick control, as well as the ability to be computer controlled. The cooling system for cameras and position motors is a standard Bernard Model 3500ss water cooler with a 50/50 mix of water and ethylene glycol.

The Camera System

The welder operators require certain information when controlling the weld. The welders must know the location of the skin edge, the key edge, along with the puddle width in order to control arc gap setting, the current setting, the pulse durations, and the torch position within the groove. The operators must also see the welding wire entry into the puddle and must have a way to review their work in order to judge surface quality and volume. The camera system provides most of these requirements with the only exception being volume. Volume must be judged by looking at the solidified weld. With experience, this too is provided to the welder by the camera image. Each welder monitors and controls two welds, having the choice of full screen or quad-split screen weld images. The quad-split screen weld image gives the ability to view the other welds which helps to train additional welders on the process, as the more experienced operator can monitor the newer. The discussion between operators and flow of information about the process is also enhanced by its use. The welds are also videotaped for periodic review.

The camera used was the Elmo EM102II CCD microcamera. It features 574 horizontal x 489 vertical pixel elements which produces a very clear image. The camera controller has automatic gain control and auto white balance control, features which are particularly valuable when operating in pulsed mode due to variable light intensity. The small physical size of the remote camera head was the reason it was chosen (4 3/4" lg. x 1" dia. including the

connector). The camera controller is mounted nearly 65 feet away from the camera head itself. The close proximity of the camera to the weld (about 2.5" away) required that the camera head be cooled. Custom camera cooling bodies were obtained from Bartz Technology in Santa Barbara, CA.

A number of filtering schemes were tried. One method was the use of enumerated welding filters. (#10, #11, #13 welding filters, etc.) This worked well in the puddle flash, but lacked a certain amount of definition in the background. Variable neutral density filters were too expensive. The final filtering scheme chosen was 1/1000 sec. shutter with a variable polarizing lense combination and a neutral density center spot. The polarizer combination is used to decrease the overall transmittance of light to the camera sensor as the orientation of the grating goes through 90 degrees of rotation about the axis of the camera body. The neutral density center spot dot is used to damp the flash of the plasma at the end of the electrode and keep the camera sensor from saturating. The dot filter was purchased through Bartz Technology. Bartz Technology also designed and built a variable polarizer, as well as a number of other devices which were tried during prototyping. The light intensity is further reduced by the iris which is set at about 1/8 of the maximum open position. Fine tuning of each camera is accomplished through two small flexible shaft gear drives designed by Fermi engineers. The drives are located on the iris and polarizer assemblies. Originally, it was thought that one camera set-up would cover three different passes, this was incorrect. Adjustment of the camera image during welding is necessary because small physical differences can result in large light intensity differences, and these variations cannot often be foreseen.

The control system for the cameras is a simple relay affair. During set-up, shuttering is disabled and the work lights (four 150 watt Reichter-Jung dual-fiber optic bundle work lamps) are enabled. While welding, the shuttering is enabled and the work lights disabled. The capability to remotely switch shuttering on and off is not a stock feature of the camera controller and had to be added by replacing the shuttering switch with a toggle at the control cabinet and lengthening the switch leads.

Depth perception is made possible by backlighting the torch. While in set-up mode, the wire feed tip and tungsten are clearly visible due to light falling on the torch from two directions. This aids the welders during automatic gap set, as shadows of the tips project on the tooling. The camera

image area is about 1 1/8" square using an Elmo JK-L15, 15 mm, F=2.0 lense. The camera is mounted about 2 1/2" away from the weld pool. With the camera sensor cooled, no adverse effects of heat have been noticed on the lenses and filters themselves. The image obtained is superior to anything the welders have seen and rivals "being there" first hand. The colors present on the edge of the plasma can be seen with this filtering scheme, should gas coverage become inadequate. This is something which cannot be said of all filtering schemes.

Conclusion

The Fermilab-SSC linear welder is producing real magnet assemblies and has been very successful in improving the quality of weld. The cost and time savings on the redesign was considerable. The bulk of this project was completed in approximately 7 months. The cost savings of the camera and monitor system was approximately half the price of a purchased turn-key camera system.